International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 9, Issue 4, Aug 2019, 1167-1172

CRASHWORTHINESS BEHAVIOUR OF CAPPED CYLINDRICAL ALUMINIUM TUBULAR STRUCTURES SUBJECTED TO LATERAL COMPRESSION

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ABSTRACT

Metallic cylindrical tubular elements have been prominent as an impact kinetic energy absorbing structures in various vehicles for their progressive deformation behaviour, long stroke and substantial energy absorbing ability. In the current research paper, systematic experiments on the crashworthiness behaviour and specific energy absorption features of deep drawn capped cylindrical aluminium tubes of different thicknesses subjected to lateral loading have been executed. Furthermore, the lateral deformation and energy absorption characteristics acquired from the quasi-static experiments were evaluated. The crashworthiness behaviour of the recommended shallow and hemispherical capped cylindrical tubes was compared to the conventional cylindrical tubes and the proposed capped cylindrical tubes absorbed more energy than the traditional cylindrical tubes. Based on the overall results obtained, it was observed that the proposed shallow and hemispherical capped cylindrical tubes showed desirable crash worthiness characteristics which is significant in the crashworthiness design of energy absorbing structures for lateral impact loading applications.

KEYWORDS: Capped Cylindrical Tube, Crashworthiness, Crash-box, Deep Drawing, Lateral Compression & Specific Energy Absorption

Received: May 25, 2019; **Accepted:** Jun 15, 2019; **Published:** Jul 20, 2019; **Paper Id.:** IJMPERDAUG2019121

Original Article

INTRODUCTION

Due to the augmentation of energy crisis and ecologicalcontamination, energy saving along with the protection of occupants has increased to one of the most fretfulconcerns for the examination and development of the latest vehicles [1]. Amongst all the methods of emission reduction and fuel saving, decreasing the overall weight of the vehicle is one of the most essential and efficienttechniques [2]. With the intention ofreducing the overall weight of the latest vehicles, dynamic research is now being devoted to extremelyadvanced designs involving thin-walled tubular structures as an energy absorber in modern vehicles [3, 4]. In this context, steel and aluminium tubes with either circular or square shaped sections had been extensively used as energy absorbers in modern vehicles [5, 6]. The significant role of energy absorber is to attenuate the kinetic impact energy by plastic crushing in an incident of collisions to reduce the large forcetransmitted to the occupants. These tubes are engaged in various mode so that when an accident take place, they collapse axially, transversely, or in combinations [7]. During transverse loading, these energy absorbing tubular elements do not experience unstablecollapsing mode and provides a smooth force–compression response and better Energy Absorbing Capability (EAC).

Majority of the previous researchers focused on the study of lateral crashworthiness behaviour and energy absorption features of simple cylindrical, conical, and spherical shaped tubes [8-10]. Only a limited amount of research works on harnessing spherical caps with the cylindrical tube has been reported. For instance, Praveen Kumar [11] have studied the lateral deformation characteristics of the plain end-capped (PE) tubes andhe reported that the Specific Energy Absorption (SEA)capacity of PE tubes is 0.8–1.6 times greater than the traditional cylindrical tubes. However, studies on the crashworthiness indicators of combined geometry cylindrical tubular structures with the cylinder-shaped tube as a base and spherical caps on the uppersegment subjected to lateral loading seem not available in pastresearch works. Nevertheless it is significant, mostly in transverse loading conditions related to crashworthiness analysis.

Hence, the main goal of the current investigation is to analyze the crashworthiness performance of the proposed shallow-spherical capped (SC) and hemispherical capped (HC) cylindricaltubes experimentally. The crashworthiness behaviour of the recommended capped cylindrical tubes was compared to the conventional cylindrical tubes and both the SC and HC cylindrical tubes absorbed more energy than the traditional cylindrical tubes. A complete discussion on their lateral crashworthiness behaviour and SEA is detailed, and the effect of tube wall thickness is then explained. The conclusion of this research study will be useful to simplify the crashworthiness regulations in analysisfor combined geometrycapped cylindrical tubes as energy absorbing elements in aircraft, automobile, railway, marine and military applications.

EXPERIMENTATION

Fabrication of Capped Cylindrical Tubes

The SC and HC cylindrical tubular elements were fabricated by the designed multi-stage deep drawing forming procedure [12]. The dimensions of the investigated tube sections are illustrated in Figure 1. The circular aluminium blanks with the thickness of 1.6, 2.04, and 3.25 mm were used in this research work.

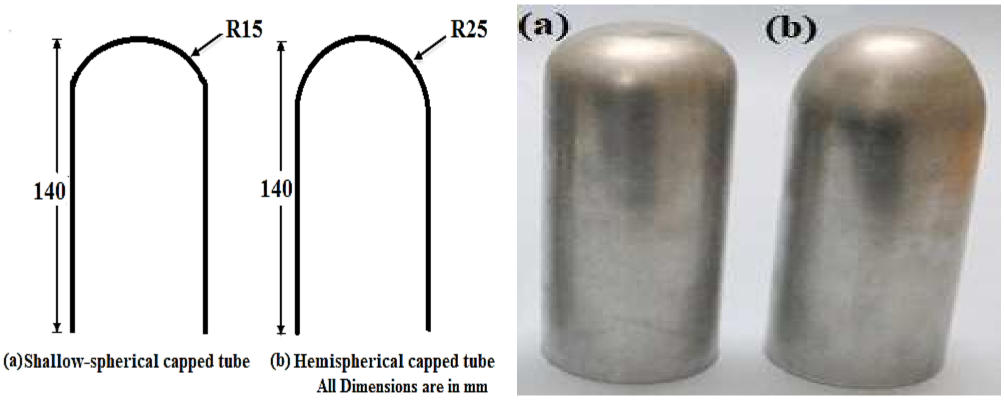


Figure 1: Fabricated Capped Cylindrical Tube Samples

The bottom edge of the formed cylindrical segment of the SC and HC cylindrical tubes was trimmed in a lathe machine. The prepared tube samples contain a shallow spherical and hemispherical caps connected to a cylindrical portion as illustrated in Figure 1.

Testing Method

With the aim of investigating the lateral crashworthiness behaviour and EAC features of the proposed SC and HC cylindrical tubes, quasi-static experiments of the fabricated tube designs were performed under identical loading

conditions. A computerized Universal Testing Machine of 80 tonnes capacity is utilized to perform the compression tests at quasi-static lateral loading. The tube specimen was properly positioned in the middle of two rigid steel discs and compressed along a lateral direction with a uniform crosshead speed of 2 mm/min as shown in Figure 2. The crushing load was progressively applied till the deformation was 80% of the diameter of the tube. The lateral crushing load and the movement of the crosshead disc were noted concurrently with the graph recording software linked to the universal testing machine. The comparison of various crashworthiness parameters [13-15] attained from the lateral crashworthiness response of all the tested tubes for both the SC and HC cylindrical tubes are displayed in Table 1.

Figure 2: Lateral Compression of Tube in UTM

RESULTS AND DISCUSSIONS

Shallow Spherical Capped Cylindrical Tube

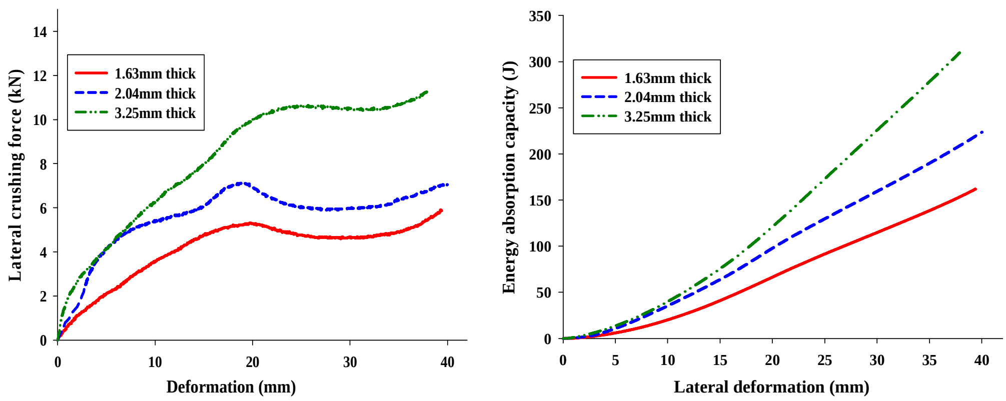
In this research article, the lateral crashworthiness behaviour and the EA features of deep drawn SC and HC cylindrical tubes were investigated using quasi-static experiments. The deformation continued with the formation of the plastic hinges, with 80% decrease in tube diameter with a final deformation of 40 mm. The comparison of the typical final crushedprofiles of the SC cylindrical tube specimens of three different thicknesses acquired experimentally is shown in Figure 3. The pictorial observation of the final buckledprofiles of the tested tubes indicates that all the SC tubesshowed similar trends of buckling in their deformation behaviour during lateral loading. SC tubes deformed with four hinge points in the four quadrants at the open end followed by the development of symmetric inward dimpling with the elliptical sections. It was observed that the collapsingpatterns of the tested tube sections is not affected by change in wall thickness values. However the shallow spherical caps in the tube resists the lateral loading which leads to absorb more energy than the traditional cylindrical tube.

Table 1: Quasi-Static Lateral Test Results

Geometry	Thickness (mm)	Mass (g)	C L (mm)	MCF (kN)	EAC (J)	SEA (J)
Shallow Spherical Capped Cylindrical Tube	1.63	93	40	4.11	162	1.74
Shallow Spherical Capped Cylindrical Tube	2.03	123	40	5.59	224	1.82
Shallow Spherical Capped Cylindrical Tube	3.25	145	40	8.18	310	2.14
Hemi Spherical Capped Cylindrical Tube	1.63	90	40	3.95	150	1.67
Hemi Spherical Capped Cylindrical Tube	2.03	121	40	5.15	210	1.74
Hemi Spherical Capped Cylindrical Tube	3.25	142	40	8.02	300	2.11

Figure 3: Comparison of Deformation Profiles of SC Cylindrical Tube

The comparative outcomes of lateral deformation and EAC characteristic curves of the SC cylindrical tubes obtained during quasi-static experiments is illustrated in Figure 4. From the curve, it is witnessed that non-appearance of initial peak force in the lateral crushingbehaviour, which is a common issue in crashworthiness behaviour of the traditional cylindrical tubes during axial loading [16-18]. For the SC tube of 1.63 mm thickness, the Mean Crushing Force (MCF) is 4.11 kN. Moreover, the EAC due to plastic deformation with the crushing length of 40 mm was 162 Joules. Similarresults with rise in magnitude were perceived for the studied tubes with other two tube wall thickness also. Among all the tested tubes of different thickness, tubes with 3.05 mm absorbed more energy around 310 Joules and SEA of 2.14 J/g. The findings in the crashworthiness characteristics of the current research work are in line with the previous studies stated by Praveen Kumar [11] for the plain end capped cylindrical tubular structure.



(a) Deformation Characteristics **(b) Energy Absorption Characteristics**

Figure 4: Crash worthiness Characteristics of SC Tubes

Hemispherical Capped Cylindrical Tube

The final deformation profiles of HC tubes with various thicknesses exposed to deformation during quasi-static lateral crushing experiments are presented in Figure 5. During the deformation of HCtubes of 1.63 mm thickness in lateral loading, four plastic hinges developed diametrically at the angular distances of 90^{o} in the non-capped side of the tested tube. Then, the hemispherical capped side of the tube initiates to yield substantively by the formation of inward dimpled hinge which resists the lateral loading and absorbs more energy. Comparablebucklingpatterns was witnessed for tubes with thickness of 2.04 mm. However the outward plastic hinge is witnessed in the tube with 3.25 mm thickness which absorbs superior energy than the other tubes tested.

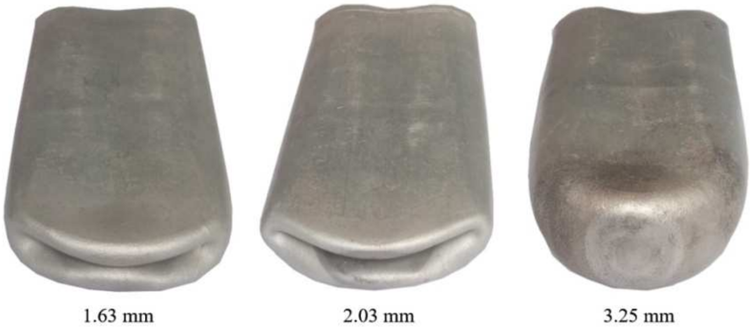
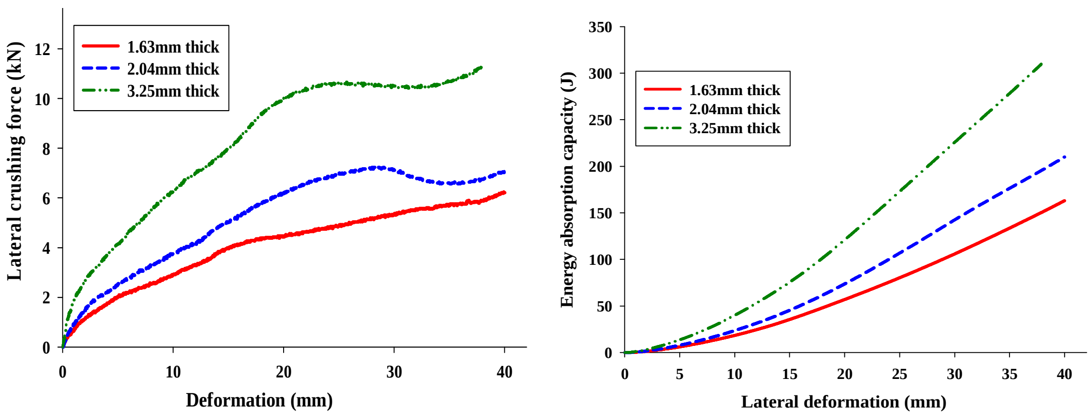


Figure 5: Comparison of Final Deformation Profiles of HC Cylindrical Tube

The comparative results of lateral deformation and EAC characteristic curves of the HC tubes attained during quasi-static experiments is illustrated in Figure 6. For the HC tube of 1.63 mmthickness, the MCF is 3.95 kN. Moreover, the EAC with the crushing length of 40 mm owing to plastic deformation was 150 Joules Similar results with rise in magnitude was perceived for the tube with thickness of 2.04 mm thickness and better results than both for 3.04 mm thickness tubes. Among all the tested tubes of different thickness, tubes with 3.05 mm absorbed more energy around300 Joules and SEA of 2.11 J/g. It is witnessed from the Figure 6 (b)that the EAC of the tubes improved with increase in thickness throughout the lateral deformation process.



(a) Deformation Character **(b) Energy Absorption Characteristics**

Figure 6: Crash Worthiness Characteristics of HC Tubes

CONCLUSIONS

The deformation behaviour and EA characteristics of the deep drawn SC and HC cylindrical tubes subjected to quasi-static lateral compression were investigated experimentally. The quasi-static lateral compression test results exposed that the crashworthiness parameters of the proposed SC and HC cylindrical tubes strongly effected by the presence of spherical caps. The important conclusions from the present research study are summarized below.

- The comparison of deformation modes in SC and HCcylindrical tubes reveals that the deformation modes are similar for thickness of 1.63 mm and 2.03 mm. However, it is different for 3.25 mm thickness tubes.
- The quasi-static crashworthinesscharacteristics of the SC cylindrical tubes are compared with the HC cylindrical tube and it was found that the EAC and SEA of the HC cylindrical tubes are slightly lower than the SC cylindrical tube.

- According to the experimental test results, crashworthiness design of the recommended capped cylindrical tubular structures is strongly validated to considerably increase the EAC and SEA. Such type of impact energy absorbing structures might find their applications such as moving vehicles, and pedestrianblockadeswhere it is exposed to transverseimpactload.

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